Los Alamos Inertial Confinement Fusion Program
FY1996 Accomplishments

Executive Summary

The goals of the Los Alamos Inertial Confinement Fusion (ICF) Program are:

- to expedite the achievement of ignition on the National Ignition Facility (NIF) by carrying out research resolving central issues of inertial confinement fusion;
- to pursue core nuclear weapons science through the development and use of ICF techniques and methods.

These goals have driven a program that includes experiments on various high energy laser facilities, advanced theoretical and computational modeling, and target fabrication materials research. Our program is designed to be synergistic with a subset of the needs of the core nuclear weapons research program. Simultaneously, it is strongly dependent on facility support and technology developed by the core weapons program. Over the last six years, we have shifted emphasis away from KrF laser driver development, and made substantial contributions in defining and resolving key issues in pursuit of ignition and completion of the Nova Technical Contract (NTC). Our achievements in FY1996 continue these contributions. We summarize the major ones here:

Target Physics, Theory, and Modeling

Completed a fundamental study of time-integrated and time-dependent radiative drive symmetry in gas-filled hohlraums including development and utilization of the re-emission-ball technique and the thin-wall hohlraum method.

Investigated saturation theories for SRS and the anti-correlation of SBS and SRS for NIF-like hohlraum plasmas.

Measured linear ablative Rayleigh-Taylor growth in cylindrical convergent geometry on experiments with the Nova laser.

Designed and began fielding a campaign of experiments for Nova to measure the feed-in and feed-out of perturbations from planar targets. This campaign will test theories of yield degradation on NIF.

Designed and began fielding a campaign on Nova to address the behavior of fabrication features or “defects” in ICF targets. These experiments involve the behavior of inherently non-linear hydrodynamic perturbations.

Continued improving theoretical robustness of NIF ignition target designs, including work on beryllium capsules and double shell non-cryogenic NIF capsules.

Developed a three-dimensional particle-in-cell plasma simulation code to model nonlinear ion kinetic effects and the role of Stimulated Brillouin Scattering in laser beam bending by transverse plasma flows.

Target Development, Fabrication and Handling

Machined one- and two-mm-diameter beryllium hemishells to NIF surface finish specifications. The fixture for the machine work is an R&D 100 Award candidate.

Demonstrated cryogenic deuterium-tritium (DT) layers of unprecedented smoothness in a toroidal cell of two-mm diameter. Root-mean-square surface roughness was measured to be less than one μm for the beta-layered process and <0.5 μm for layers formed with heat added to the interior of the cell.

Filled glass micro balloons with up to 20 atm of DT at Weapons Engineering Tritium Facility (WETF). When shot at Omega, these targets produced the world's highest neutron yield. Los Alamos is replacing the capability of Mound which is being closed down.

Manufactured over 800 Trident targets and over 130 Nova targets including developing high pressure gas-filled hohlraums and cylindrical capsule fabrication with perturbations of less than one μm.

Glass Laser and Related Technology Development

Demonstrated Rapid Pad Polishing technique on half-scale NIF slabs and began work on full-scale NIF slabs.

Los Alamos Inertial Confinement Fusion

FY1996 Accomplishments

I. Introduction

The Los Alamos Inertial Confinement Fusion (ICF) Program has two principal goals:

- to perform research that is central to the achievement of ignition on the National Ignition Facility (NIF)
- to develop and utilize ICF techniques and methods in pursuit of core nuclear weapons research.

These goals have driven a program that includes experiments on various high energy laser facilities, advanced theoretical modeling, and target fabrication materials research. The Los Alamos ICF Program has been designed to be synergistic with a subset of the needs of the core nuclear weapons research program. Simultaneously, Los Alamos ICF research is strongly dependent on facility support and technology developed by the "core" weapons program.

In response to the 1990 National Academy review of the ICF Program, Los Alamos has shifted emphasis from KrF laser driver development to a focus on indirect drive target physics and its near term goal of ignition. Over the last six years, Los Alamos has made substantial contributions in defining and resolving key issues in pursuit of ignition and completion of the Nova Technical Contract (NTC). While continuing our strong collaboration with and critique of LLNL on many issues, we have taken responsibility for major elements of the target physics research crucial to ignition. We have helped to strengthen the field by establishing strong, productive collaborations with LLNL on Nova and both Rochester and LLNL on Omega. In addition, numerous joint diagnostic prototyping and calibration efforts have been undertaken our own Trident laser system. Since the completion of the NTC in the last year, we have transitioned our research program to utilize ICF facilities to investigate physics issues of interest to the core nuclear weapons research program while continuing our research directed toward ignition. In this report, we outline our accomplishments from FY1996.

Over the last six years, Los Alamos has made major contributions to key research in the pursuit of ignition and the application of ICF technologies to weapons problems. Our research program in FY1996 built upon these accomplishments. Our foremost accomplishments since 1990 include the following:

- Leadership of the radiation drive symmetry campaign on Nova.
- Development of several totally new methods for the diagnosis of time dependent symmetry including re-emission balls and symmetry capsules; developed thin wall hohlraums for accurate measurements of hohlraum and capsule emission imaging.
- First direct observations of beam bending in the presence of plasma flow on Nova hohlraums and Trident, and the first theoretical explanation of this phenomena.
- Fielded the first gas-filled hohlraums at Nova.
- Evolved laser plasma instability research beyond the linear theories of the past to do routine non-linear 3-D modeling of plasmas, including laser hot spot effects.
- Performed experiments which have helped define the instability thresholds for SRS and SBS and the saturation mechanisms for SRS in NIF-like plasma conditions.

- Pioneered both the integrated modeling technique for modeling indirect drive targets and the detailed numerical simulation technique for assessment of hydrodynamic instabilities and applied both to improving NIF target robustness.
- Initiated and developed the baseline beryllium NIF target design which has significant promise for increasing ignition design robustness.
- Developed an entirely new and powerful method, cylindrical implosions, for diagnosing hydrodynamic instabilities in convergent geometry; utilized this method to perform the first observation of feed through of instabilities from the ablation surface.
- Evolved hydrodynamic theory and experiments beyond the linear non-converging flow Rayleigh -Taylor regime to study converging flows and non-linear growth of hydrodynamic instabilities.
- Demonstrated cryogenic DT layer thickness and smoothness consistent with NIF target specifications in a surrogate cylindrical geometry.
- Brought to fruition an unanticipated level of diagnosis of plasmas and implosions. Major diagnostic systems included the ion temperature and plasma instability imaging.
- Demonstrated a new mechanism for the seeding of the SBS instability; demonstrated the dependence of stimulated scattering on acoustic damping.
- Developed a wide suite of target fabrication capabilities to support construction of over 200 innovative Nova and Omega targets and 1200 Trident targets each year.
- Developed and maintained Trident to support a wide range of fundamental ICF and ICF related studies including pioneering experiments in plasmas, materials research, and diagnostic development.

Today, the Los Alamos ICF program has five principal elements:

Hohlraum Plasma Dynamics seeks to improve the understanding of indirect drive necessary for ignition and the application of indirect drive for core weapons experiments

Capsule Implosion and Hydrodynamic Physics addresses hydrodynamics issues common to implosion physics for ignition and improving hydrodynamics predictive capability for the core weapons program

Ignition Target Fabrication Technology develops technology required for building and fielding ignition targets and targets for ongoing experimental campaigns

Computational Assessment improves prediction of ICF target behavior for ignition and advances computational capability needed for core weapons utilization of laser facilities, and

Target Experimental Technology concentrates on development of methods and techniques essential in utilizing ICF facilities including diagnostic and instrument development, optical fabrication technology development, and the operation of the Trident laser facility.

Within the five elements, we have briefly outlined our principal accomplishments addressing critical ignition issues and Stockpile Stewardship science. Many of these campaigns have involved collaborations with Lawrence Livermore National Laboratory, University of Rochester/Laboratory for Laser Energetics, General Atomics, and to a limited extent Sandia National Laboratory and the Naval Research Laboratory. We outline our principal accomplishments from FY1996 in this report.

II. Hohlraum Plasma Dynamics

Understanding hohlraum plasma dynamics is critical to attaining ignition as well as for effectively utilizing indirect drive for weapons physics experiments. Laser-heated hohlraums are the mainline approach for driving high performance implosions and for heating and accelerating packages used in weapons physics experiments. In indirect drive, the laser couples its energy into a cavity (hohlraum) made of a material with high atomic number. Such materials efficiently convert laser energy to x-rays and create a radiation environment which can be tailored to drive implosions or radiatively heat nonimploding targets. Plasma evolution within a hohlraum is very complex involving many physical processes. In order to optimize indirect drive for ignition and weapons physics, we must have a thorough understanding of radiation illumination symmetry and laser plasma instabilities.

Radiation Symmetry and Hohlraum Characterization

Significant progress has been made in developing methods for measuring and controlling the symmetry of the hohlraum radiation field that heats and implodes capsules. To achieve ignition on NIF, it is essential to limit radiation asymmetries on the capsule to less than 2% time-averaged over the duration of the drive. In addition, time-dependent fluctuations in symmetry (over a few nanoseconds) must be controlled to better than 10% rms. Control of these symmetry fluctuations will be accomplished on NIF through beam phasing (independent laser beam power control) of the inner and outer cones of illumination.

The Los Alamos program initiated the first experiments with gas-filled hohlraums in 1993 at Nova. Gas-filled hohlraums are utilized in all of the current baseline designs for ignition targets. The Los Alamos program has studied all aspects of gas-filled hohlraum performance including laser energy deposition, laser plasma instabilities, x-ray radiation (drive) symmetry [N. D. Delamater, *et al. Phys. Plasmas* **3**, 2022(1996)] and overall energetics. In the last year, symmetry research has centered on characterizing, quantifying, and controlling the deposition of laser energy, beam steering mechanisms in Nova hohlraums and fielding the first symmetry experiments on Omega.

Future experiments will emphasize detailed understanding of physical processes which affect symmetry. New illumination geometries, including multiple laser cone irradiation to be used in NIF and nonconventional hohlraums (such as tetrahedral) will be explored. Future experiments using Nova and Omega will study the effect of laser deposition beam smoothing on beam steering and aspects of beam phasing. All symmetry experiments serve as important benchmarks for improving radiation-hydrodynamics predictive capability.

Accomplishments:

- Completed the development of the re-emission symmetry technique and quantitatively demonstrated its validity in the measurement of early time radiation drive symmetry. [N. D. Delamater, *et al., PRE* **53,** 5240 (1996)]

  Background: The re-emission technique utilizes a non-imploding high-z ball instead of a capsule. The radiation at the capsule position can be monitored as a function of time by imaging the re-emission of the ball. This technique is utilized for monitoring early time hohlraum symmetry.

- Fully substantiated the thin-wall hohlraum method for complete integrated diagnosis of hohlraum drive and implosion characteristics. [N. D. Delamater, *et al.,* submitted to *PRL*]

  Background: The thin wall hohlraum method, utilizing a thin gold wall externally supported by plastic, allows imaging of both x-ray emission from the laser spots and the capsule implosion. Thereby, this method provides a means for measuring both the drive characteristics of the hohlraum (such as beam positions) and the implosion of a capsule in essentially the same geometry used in ordinary implosion experiments. The technique was used to study the phenomena of beam deflection in gas-filled hohlraums.

- Completed the first phase in the development of implosion sampling (known as "symmetry capsules") as a method of measuring time dependent drive symmetry. [N. D. Delamater, *et al.*, *Phys. Plasmas* **3**, 2022 (1996)]

  Background: In order to obtain time dependent symmetry information from implosion capsules with varying ablator thicknesses and thus varying implosion times are utilized. The symmetry capsules give a measure of the time integrated symmetry though the time of their implosion. The "symmetry capsule" technique gives time resolved symmetry information (over much of the drive pulse) at the level of accuracy needed for diagnosing ignition capsules.

- Demonstrated, through a suite of LASNEX calculations, that beam motion in the presence of plasma flow could account for all the observed changes in imploded capsule symmetry. These calculations show LASNEX can reproduce the time dependent symmetry database, helping to rule out effects other than beam bending. Integrated target modeling (laser deposition + capsule + hohlraum) was used in these calculations. [E. Lindman, *et al.*, *BAPS* **41**, (1996)]

  Background: Time integrated symmetry experiments in gas-filled hohlraums show a 150 micron shift in laser pointing is required to obtain a symmetric capsule implosion as compared to laser pointing for round images in vacuum hohlraums.

- Performed the first proof of principle experiments using multiple beam cones using Omega. The experiments demonstrated the indirect drive capability at Omega, including the ability to point beams and align hohlraums in the required indirect drive geometry (Fig. 1). Implosion symmetry scans were performed which verified Nova-like performance (Fig. 2). New capabilities afforded by more beams were demonstrated using the re-emission diagnostic to observe improved azimuthal symmetry with fifteen beams per laser ring. The ability to treat the symmetry in a hohlraum using multiple beam cones by using the weighted average spot position was also verified. [T. J. Murphy, *et al.*, *BAPS* **41**, 1420 (1996)]

- Designed an experimental campaign, to commence in February 1997, to address the value and possible advantages of spherical hohlraums with tetrahedral illumination symmetry. These experiments will be performed on Omega, and will allow the utilization of all 60 beams for indirect drive. The experimental campaign will address the possible time-dependent symmetry advantages, as well as avenues to higher radiation temperature hohlraums. Additionally, we began a collaborative effort in 3-D viewfactor modeling of tetrahedral hohlraums utilizing newly developed modeling tools.

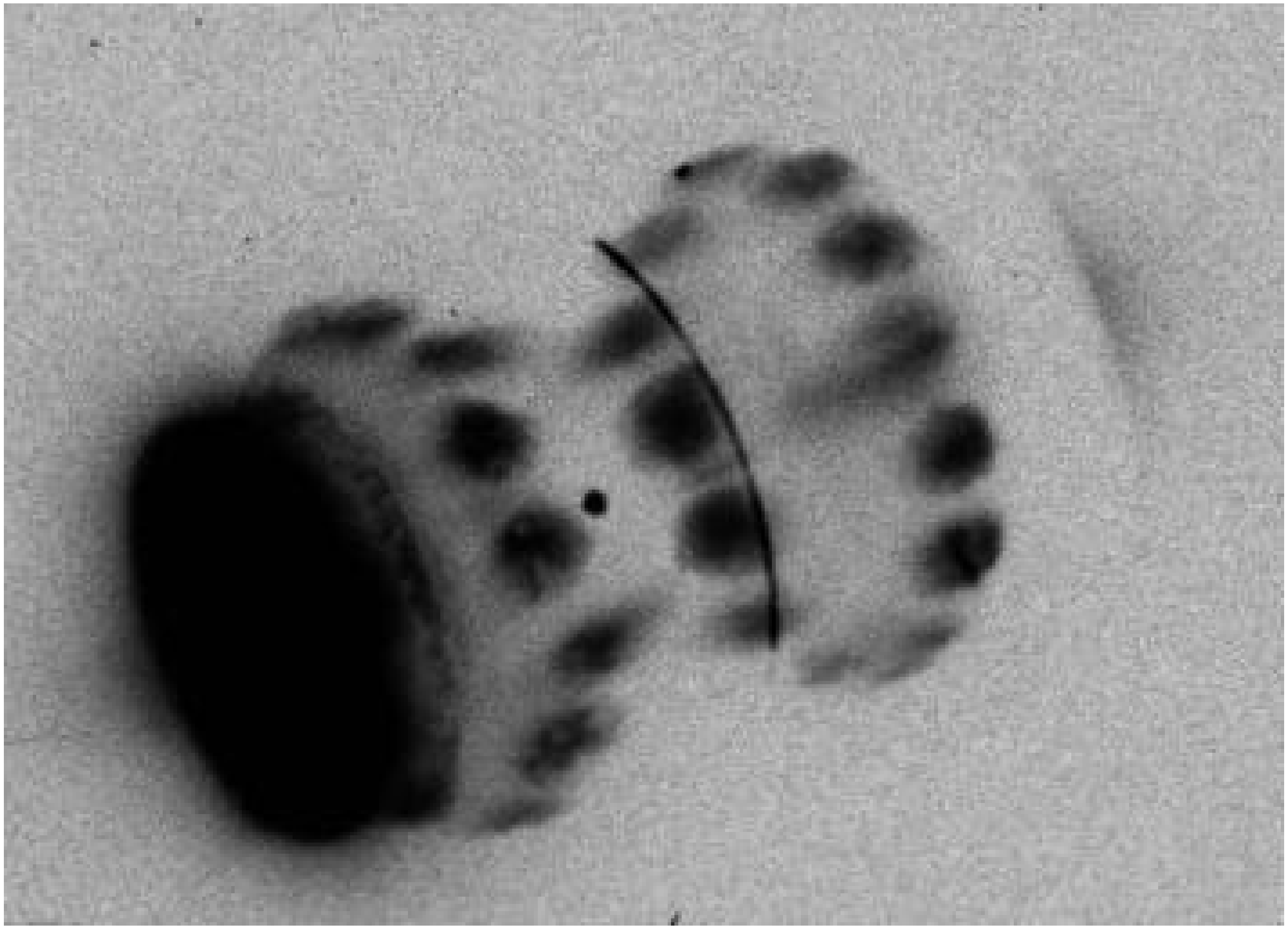

Fig. 1. X-ray image of thin-wall hohlraum tested at Omega laser. Two circles of laser spots, with 15 spots per circle, are evident at either end of hohlraum. Strong plasma emission is visible from near end of hohlraum. Arc of plasma emission is faintly visible beyond far end of hohlraum. In this negative image, emission from imploded capsule is seen as dense black spot near center of hohlraum. Bright arc near center of hohlraum shows seam where two halves of hohlraum are joined during fabrication.

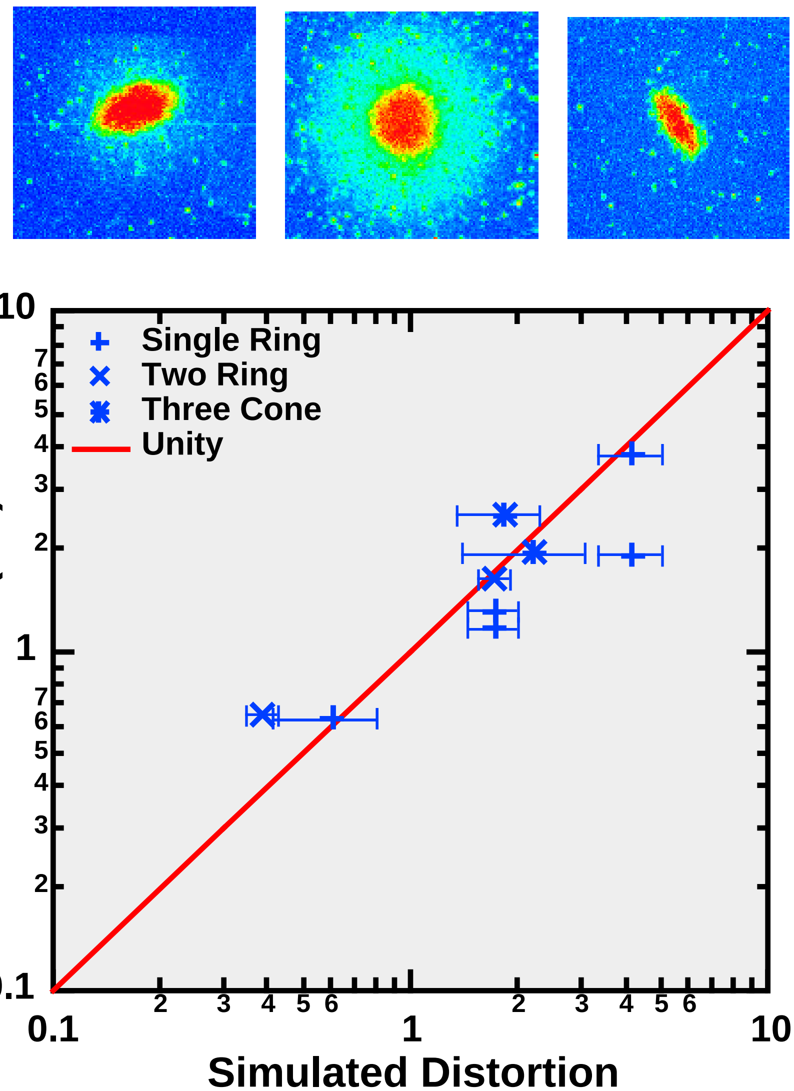

Fig. 2. *Upper panel*: images of imploded capsule cores from Omega symmetry experiments, showing (from left to right) prolate (a/b < 1), round, and oblate (a/b > 1) implosions. Hohlraum axis is about 20 ^{O} from horizontal. *Lower panel*: Comparison of simulated and observed distortion of imploded capsule core for Omega symmetry pointing scans. The observed results agree with modeling and Nova experience, and show that multiple rings of beams behave similarly to single rings.

Laser Plasma Instability Generation

Laser-plasma instabilities can scatter laser light into undesirable directions including backwards out of the hohlraum. This can be deleterious to hohlraum energetics as well as a source of capsule implosion asymmetry. In order to achieve ignition, laser plasma instabilities must be controlled. To date, we employ a phenomenological and often qualitative understanding of self-focusing, stimulated Raman scattering (SRS), and stimulated Brillouin scattering (SBS). We cannot quantitatively predict laser plasma instability levels for nominal plasma conditions on NIF nor can we confidently conclude that 500 eV radiation temperature hohlraums will be a viable tool on NIF for weapons physics. Greater understanding of the processes controlling the nonlinear saturation levels of SBS, SRS, filamentation and two-plasmon decay (TPD) is the main challenge.

Los Alamos experiments investigate laser plasmas instabilities in open geometries on Trident and in toroidal hohlraums on Nova. Toroidal hohlraums were specifically designed to establish NIF-like density, temperature, and scale-lengths. Toroidal hohlraums were the first hohlraums to be fielded with gas-fills. Characterizing plasma conditions in toroidal hohlraums has required development and utilization of sophisticated spectroscopic techniques. Additionally, a large suite of new diagnostics has been brought to bear to characterize of laser plasma instability levels. Los Alamos diagnostics include a spatial discriminating optical spectrometer (SDOSS), a optical axial imager, a oblique scatter array (OSA), and an optical imaging diagnostic along the interaction beam (FABSI).

More experiments are essential to formulating a quantitative, predictive capability for these processes. Ongoing experiments are bringing new diagnostics to bear on this problem to further constrain and guide theoretical modeling. We have just added imaging of the scattered light to the present diagnostic arsenal of calorimetry and spectroscopy. Most of these shots will be done at Nova, where a recent major investment in new diagnostics has been made.

<u>Accomplishments:</u>

- Verified experimentally [J. C. Fernandez, *et al.*, *PRE* **53**, 2747 (1996) and R. G. Watt, *et al.*, *Phys. Plasma* **3**, 1091 (1996)] a theoretical model [H. A. Rose and D. F. DuBois, *PRL* **72**, 2883 (1994)] for SBS onsets on realistic laser beams with spatial smoothing by random phase plates and the corresponding statistical distribution of laser hot spots.

- Demonstrated experimentally [J. C. Fernandez *et al.*, submitted to *PRL*] in Trident experiments with long-scale plasmas that non-linear SBS saturation is not a robust process independent of initial conditions. Instead, the saturated level depends on the level of the seed perturbation amplified by SBS. By externally injecting a modest seed, "saturated" SBS levels were increased by a factor of up to 10.

- Showed experimentally [J. C. Fernandez, *et al.*, *PRE* **53**, 2747 (1996)] that non-linear saturated levels of SBS in long-scale hohlraum plasmas with NIF-relevant plasma conditions depend on the damping rate of ion acoustic waves. This effect is not yet understood theoretically.

- Demonstrated experimentally [J. C. Fernandez, *et al.*, *PRL* **77**, 2702 (1996)] that non-linear saturated SRS levels depend on ion acoustic damping. This supports theoretical work [e.g., B. Bezzerides, *et al.*, *PRL* **70**, 2569 (1993)] that SRS can saturate via secondary decay processes of the SRS daughter plasma wave.

- Showed that SRS and SBS minimization place conflicting requirements on the desired acoustic damping to be chosen for NIF hohlraums (see above) (Fig. 3).

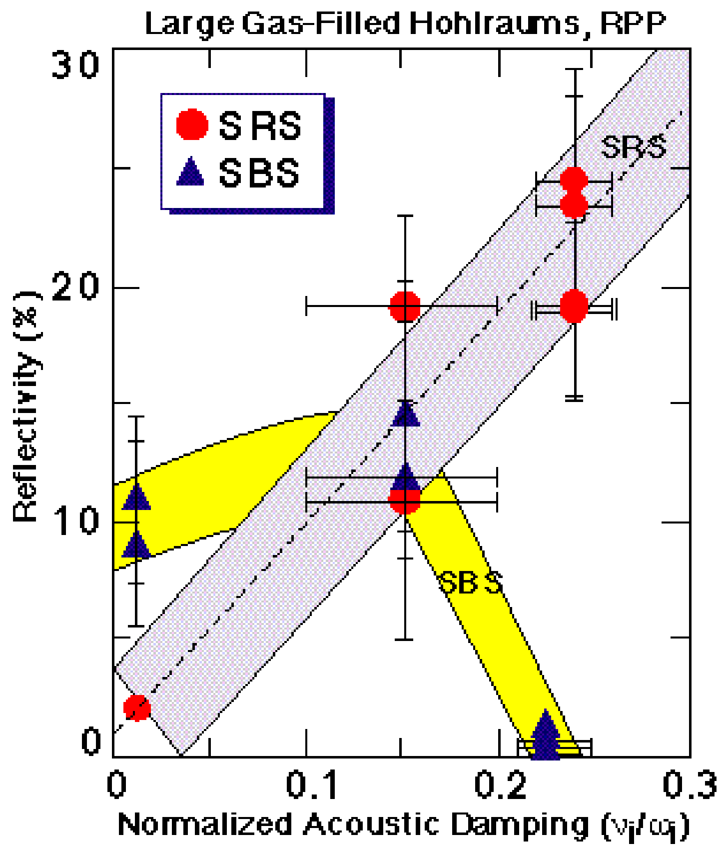

Fig. 3. Observed variation of SRS and SBS reflectivity as functions of acoustic damping in large gas-filled Nova hohlraums. For ν_i/ω_i > 0.15, minimization of SRS and SBS lead to conflicting requirements on acoustic damping.

- Verified experimentally [J. C. Fernandez, *et al.*, submitted to *Phys. Plasmas*] that the theoretical model [H. A. Rose and D. F. DuBois, *PRL* **72,** 2883 (1994)] for SBS onsets also applies to SRS.

- Verified experimentally [J. C. Fernandez, *et al.*, submitted to *Phys. Plasmas* ; J. C. Fernandez, *PRL* **77**, 2702 (1996)] that the levels of non-linearly saturated SRS are insensitive to electron density over a wide range of interest for NIF.

- Achieved electron temperatures of up to 6 keV in Nova hohlraums (demonstrated with novel spectroscopic methods [B. H. Failor, *et al.*, *BAPS* **41**, 7, 1390 (1996)]) to explore laser-plasma instability processes in the broad range of conditions expected in NIF hohlraums.

- Successfully imaged SRS and SBS sidescattered light from Nova hohlraums [J. C. Fernandez, *et al.*, submitted to *Phys. Plasmas*, 1996 and W. M. Wood, *et al.*., submitted to *PRL*] with sub-ns exposures using the Axial-Imager Diagnostic. The SRS data are been used to improve the accuracy of LASNEX radiation-hydrodynamics simulations. The SBS data are been used for a study of collective SBS by multiple beams. [D. F. Dubois, *et al.*, *Phys. Fluids B* **4**, 241 (1992)]

- Measured SBS sidescatter levels from Nova hohlraums using the Oblique Scatter Array diagnostic. The measured sidescatter losses are sufficiently small to not change plasma conditions significantly relative to LASNEX simulations which ignore such losses.

- Demonstrated directly on a Trident experiment that plasma flow transverse to a laser beam can deflect the beam [B. S. Bauer, submitted to *PRL*; J. C. Fernandez, *et al.*, submitted to *Phys. Plasmas*]. The deflection is resonant at the sonic speed. There is also a threshold intensity for large deflection (about 10 degrees), interpreted as filamentation enhancing the effect, as predicted theoretically [H. A. Rose, *Phys. Plasmas* **3**, 1709 (1996)].

- Quantitative spectroscopic methods were developed for the measurement of plasma conditions in laser-heated hohlraums. These measurements have been very useful in benchmarking over-all hohlraum modeling and in developing plasma instability models.

III. Capsule Implosion and Hydrodynamic Physics

Accurate computational modeling of the hydrodynamics of imploding capsules is crucial for an ignition demonstration in ICF, because of the importance of such phenomena as accurate shock-wave timing, radiation and thermal electron ablation, the development of the central hot core, and the effect of hydrodynamic instability. Furthermore, improved understanding of implosion hydrodynamics is important for the enduring nuclear stockpile, and is an area in which ICF can make valuable contributions to predictive capability in core weapons programs.

In the past, much of international ICF hydrodynamics research has concentrated on the linear (i.e., small-amplitude) phase of instabilities in planar geometry. Recently, however, the Los Alamos program has quantitatively demonstrated a major new diagnostic/ measurement technique - the use of cylindrical implosions in hydrodynamic experiments. This technique has advanced hydrodynamic instability work into the nonlinear regime and also provided the first experimental tests of the feed through of perturbations generated at the ablation front to the inner wall of the imploded shell. This advance into the nonlinear regime is also crucial in enhancing the relevance of hydrodynamic research to weapons issues. Also, with recent advances in our ability to calculate NIF capsule performance, we have identified two new NIF hydrodynamics issues. These are:

- feed out of perturbations at the fuel gas-ice interface and subsequent feed in of perturbations through the capsule shell;
- non-linear behavior of fabrication defects. This is another issue of significant relevance to the weapons program and an example of synergism between ICF and core weapons.

Additionally, we continue research on the foam buffering technique, which can potentially smooth laser nonuniformities for direct drive. The success of the alternative direct drive approach to ignition on NIF depends on avoiding significant growth of Rayleigh-Taylor (RT) instabilities seeded by residual laser nonuniformities. Suppression of RT growth to acceptable levels is potentially possible either by creating very smooth drive beams by laser optical techniques, or by constructing robust targets able to survive residual nonuniformities in the drive beams, or both. One possible robust target technique, potentially capable of surviving both early time imprint prior to the effective smoothing time of an optically smoothed beam, and small scale static nonuniformities, is foam buffering. Use of foam layers surrounding targets creates a thermally conducting low density plasma around the solid shell of the capsule, to isolate the laser absorption region from the ablation surface, and permit lateral thermal transport to smooth out laser nonuniformities. Such a technique may be critical to successful direct drive ignition on NIF may create more efficient direct drive in the heating and acceleration of packages utilized in hydrodynamic weapons physics experiments.

Accomplishments:

- Measured perturbation growth factor of 15 in convergent-geometry instability experiments at Nova, using cylindrical implosions (Fig. 4), and found preliminary evidence for compressible Bell-Plesset instability (a generalized form of Rayleigh-Taylor instability unique to convergent geometry, i.e., cylindrical or spherical flow, as opposed to planar flow). Demonstrated accurate LASNEX modeling of perturbation growth during the acceleration and coasting phase of the implosion. Demonstrated linearity of growth over a range of a factor of 4 in initial perturbation amplitude. Observed mode coupling between long-wavelength drive asymmetry and short-wavelength surface perturbation. [W. Hsing, *BAPS* **41**, 1529 (1996); C. W. Barnes, *et al.*, *BAPS* **41**, 1525 (1996); and invited talk/paper to be published in *Phys. Plasmas*]

  Background: NIF capsules are highly unstable during implosion, so it is crucial to verify our understanding of instability processes and our ability to control them. Experiments in convergent geometry are necessary because of numerous unique effects which do not occur in planar geometry. Our cylindrical implosion experiments permit direct imaging of growing perturbations in convergent geometry, allowing stringent assessment of the accuracy of LASNEX simulations.

- Designed and fielded experiments that obtained the first observations of “feed out”, or the coupling of rear-surface Richtmyer-Meshkov instability with front-surface ablative Rayleigh-Taylor instability in planar foils at Nova. Observed phase reversal of the perturbation caused by Richtmyer-Meshkov instability and subsequent rapid growth *via* ablative Rayleigh-Taylor instability. Demonstrated accurate LASNEX modeling of the growth of the fundamental wavelength, and identified the need for greater mesh refinement in calculations of higher harmonics. Identified the generation of strong acoustic waves by Richtmyer-Meshkov instability in calculations of short-wavelength perturbations in NIF shells. [N. M. Hoffman, *et al.*, *BAPS* **41**, 1561 (1996); D. P. Smitherman, *et al.*, *BAPS* **41**, 1561 (1996); R. E. Chrien, *et al.*, *BAPS* **41**, 1562 (1996)]

  Background: In calculations of NIF capsules, perturbations on the inner surface of the shell propagate outward or “feed out” to the ablation surface where they are amplified, and later “feed in” again to the inside of the capsule, interfering with ignition. Thus, the feed out/feed in mechanism has an important effect on NIF capsule performance. The details of this process involve the coupling of Richtmyer-Meshkov instability on the inside of the shell with ablative Rayleigh-Taylor instability at the outside of the

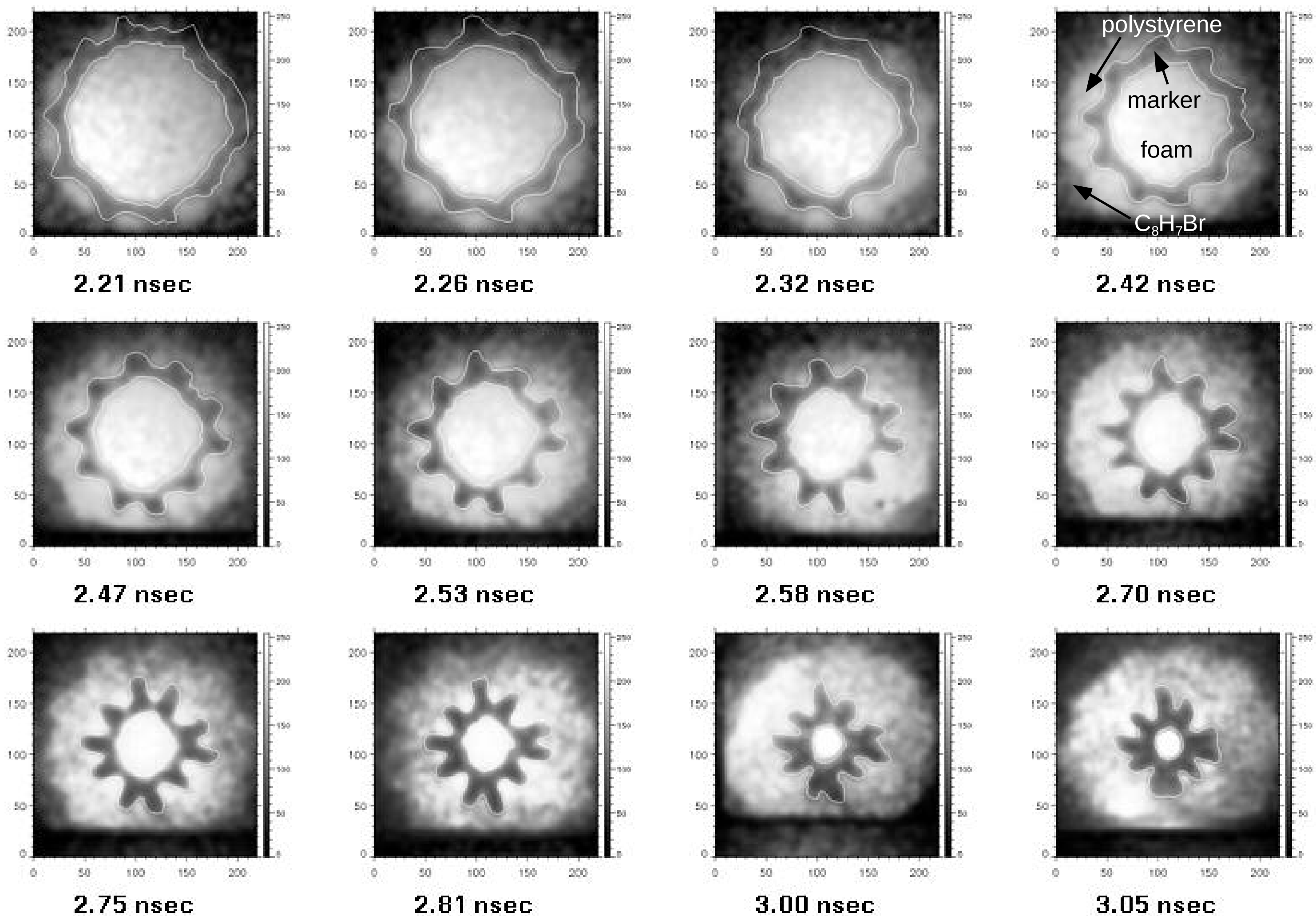

Fig. 4. A sequence of gated x-ray backlighter images from a Nova cylindrical implosion. The initial perturbation had amplitude of 1.7 µm and mode m = 10. The hohlraum drive was PS26. The chlorinated polystyrene marker layer interfaces are highlighted.

shell. Because of the importance of hydrodynamic instabilities in NIF implosions, it is necessary to verify our understanding of this process by means of Nova experiments which can approximate the expected phenomenology on NIF.

- Demonstrated that initial defect scale length can grow laterally by factor of ~5, in preliminary Nova experiments (Fig. 5) to measure the shock planarity from planar targets containing defects (joints and gaps). Found semi-quantitative agreement between both LASNEX and RAGE calculations and experimental data for deviations of shock and ablation fronts from planarity. Identified general physical mechanisms of shock front structures for joints at both higher and lower density than the surrounding target material. Defined critical experiments for more detailed comparison between theory and experiment. Established connections through simulations between shock front structures in the NIF target and on Nova. Identified the need for experiments at lower drive temperatures to investigate possible low temperature effects for NIF target defects. [S. R. Goldman *et al.*, *BAPS* **41**, 1353 (1996); M. D. Wilke, *et al.*, *BAPS* **41**, 1353 (1996)]

  Background: Some NIF ablator materials require fabrication techniques that lead to unavoidable isolated perturbations such as joints, chamfers, plugs, and/or fill tubes. A distinguishing feature of such defects is that they are initialized in the nonlinear regime; that is, their initial amplitude is comparable to or even much larger than their wavelength. Thus, the growth of such a perturbation occurs in both wavelength and amplitude, so that defects of rather small initial scale can become quite large. An assessment of the effect of fabrication defects in ablators is critical to using these materials for an ignition demonstration. We will exercise our predictive capability for a variety of defects that could harm capsule performance on NIF.

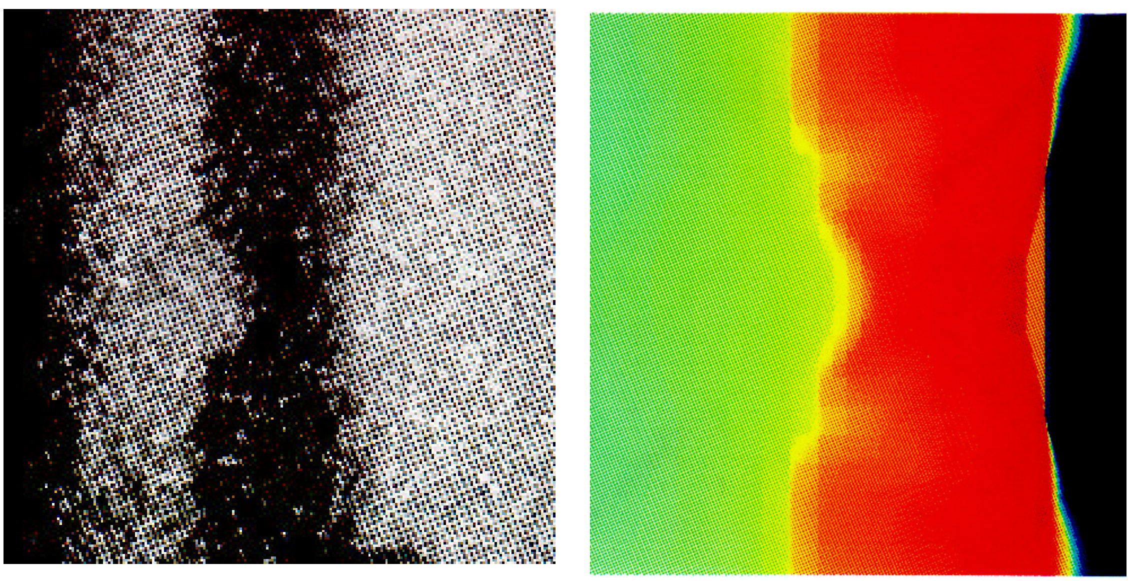

Fig. 5. Observation (left) and RAGE simulation (right) of a gap experiment in brominated polystyrene, for a gap of 18 μm initial width and 30 μm initial depth. Simulated image is 175 μm on an edge. The planar foil is heated from the left by hohlraum radiation. The shock in the region of the gap lags the shock far from the gap. The gap has widened to 2.5 times its initial width at this time. The calculated velocities of the shock wave and radiation wave are in agreement with the observation, both near the gap and far from the gap.

- Began design of cylindrical implosion experiments to be carried out with direct drive at the Omega laser. Surveyed wide range of possible cylinder designs and assessed criteria for instability growth. Identified suitable diagnostic and illumination geometries for fielding direct-drive cylinders. Wrote a laser-illumination code to permit optimizing the uniformity of laser illumination on cylinder.

Background. Imploding-cylinder instability experiments at Omega are the next step in our campaign to validate our theoretical and computational modeling of hydrodynamic instability in convergent geometry. Implosion experiments at modest convergence can be driven more efficiently with direct drive at Omega thus enabling high velocities and/or larger sample sizes and allowing access to larger regimes of implosion parameter space. We expect that these new experiments can be carried out with larger space and time scales than past experiments, permitting better resolution of structures and the use of higher perturbation modes. In addition, cylindrical experiments may provide an important vehicle for testing some aspects of cryogenic target implosions.

- Conducted the first high resolution spectroscopic measurements in the foam buffered program of the decompression of a solid foil in the presence of a low density foam, both with and without an x-ray preheat layer on the surface of the foam. This experiment utilized reflective 1-D imaging to illuminate a spectrally dispersed x-ray streak system, providing the first quantitative measurement of the decompression level in the foil by studying the density and temperature of a buried gold layer as a function of time and burial depth, using absorption spectroscopy. Initial comparisons to the NYM code and a spectroscopic post-processor to that code show excellent agreement. The technique provides a new tool in the arsenal for understanding the interaction physics of these layers.

  Background: Foam buffers allow lateral thermal transport to smooth laser-drive nonuniformities, avoiding disruption of an implosion by strong hydrodynamic instability. The foam buffered direct drive program has been examining such buffers, created from a low density plastic foam, at both 527 nm and 351 nm drive wavelength. This program has conducted experiments in planar, cylindrical, and spherical geometry to study both the interaction physics and the engineering aspects of creating the low density foam coated targets. Planar experiments at 527 nm have been very successful at eliminating both speckle imprint and larger scale static nonuniformities [M. Dunne, *et al.*, *PRL* 75(21), 3858 (1995)]. This method, which has predominantly been developed on the Trident laser, may also make possible the use of more efficient direct drive in the heating and acceleration of packages utilized in hydrodynamic weapons physics experiments.

- Performed the first semi-quantitative measure of the effect of a gold layer used to preheat and homogenize a foam buffer into a hot plasma prior to laser absorption in the buffer. This test, based on an analysis of the growth of individual instability modes present in the solid at late time, showed that for solid density 10 mm thick CH shells gold preheating in layers more than 200-250 A in thickness lead to significant decompression and reduction in growth.

- Initiated the first planar experiments at 351 nm looking at the effects of 30 and 50 mg/cc polystyrene foams. These experiments show definitive reduction in the short wavelength modes but leave significant uncertainty at the longer wavelengths. Experiments to be conducted on the Omega laser are scheduled for December 1996 to resolve some of the questions surrounding the behavior of these targets which used a ramped pulse in place of the more normal flattop.

- Conducted the first spherical implosions using a foam buffer and a modern high power, short wavelength laser at Nova to test both the engineering of the target and get a preliminary assessment of the effect of the foam buffer. [R. G. Watt, *et al.*, submitted to

Phys. Plasmas] These foam buffered implosions, when compared to clean 1-D LASNEX calculations, showed an improvement of a factor of several in YOC (observed yield divided by clean calculated yield), relative to the YOC of a bare capsule driven to the same final convergence ratio, despite the existence in the Nova illumination geometry, of nonuniformities much larger in scale than the foam thickness. [D. C. Wilson *et al., BAPS* **41**, 1480 (1996); R. G. Watt *et al., BAPS* **41**, 1526 (1996)].

- Continued design of a spherical implosion series at 351 nm with improved illumination symmetry and beam smoothness for the Omega laser. The comparison target for this series will correct some deficiencies in the Nova experiment, by attempting to hold *both* the final convergence ratio and the inflight aspect ratio the same between the buffered and bare targets.

  Background: It is important to separate the effect of foam imprint removal from the other possible physics effects such as adiabat changes and differences in drive acceleration history between the foam and bare targets, which can cloud the interpretation. Both of the latter effects reduce the growth rate of Rayleigh-Taylor instabilities and can lead to misinterpretation of any observed reduction in growth. These issues are addressed in independent planar experiments at 351 nm in parallel to the spherical design effort.

IV. Ignition Target Fabrication Technology

ICF target fabrication is vital for attaining ignition on NIF. This field has long been a fertile mix of complex materials science and characterization development. Although the national ICF Program has made excellent progress in advancing the state of target fabrication we are far from being able to produce and characterize actual NIF targets. We will continue our efforts in the materials science of beryllium and its alloys, and in the properties of solid DT as they apply to fabrication of ignition capsules. Both the capability to fabricate beryllium shells and to perform the high pressure fills required of NIF ignition capsules overlap with capabilities required for the nuclear weapons mission at Los Alamos. Fabrication exploits the synergism of core weapons research and ICF because many of the scientists working on these complex problems are also working on the analogous weapons problems involving the same materials, such as fire resistance and neutron generation. In addition, the fabrication of targets for ongoing experiments at the three laser driver facilities in the program, Nova, Omega, and Trident, require advanced materials science efforts in, for example, foam fabrication and precision machining.

<u>Accomplishments:</u>

- Machined one and two mm diameter beryllium hemishells to NIF surface finish specifications (Fig. 6). The fixture for the machine work was a R&D 100 Award candidate. The fixture did not win the R&D 100, but it is a very promising piece of technology that may have application in our Pit rebuild program and in the machining of large optics and high explosive. [P. L. Gobby, *et al.*, to be published in the *Proceedings of the ANS Embedded Topical Conference on Fusion Technology*, (1996)]

- Fielded foam buffered glass spheres on Nova. Polystyrene hemishells were machined and assembled around the filled glass shells and assembled into a direct drive target. Recently machined a foam hemishell 900 μm in diameter and 100 μm thick from 30 mg/cc polystyrene foam. [J. R. Duke Jr, *et al.*, 11th Target Fabrication Specialist's Meeting, WA, (1996)]

- Extended cylindrical capsule fabrication to mode 14 perturbations and perturbations of less than one micron amplitude. Developed a novel technique for machining the perturbations in the form of pure sine waves rather than the 360 facets used previously (this was an improvement over the 30 facet technique of 11/95). [P. L. Gobby, *et al.,* presented at the 18th World Conference of the International Nuclear Target Development Society, France (1996), to be published in *Nuclear Instruments and Methods*.]

- Fielded high pressure (five atmosphere) gas-filled hohlraums for LPI with 0.93 micron polyimide windows and 0.3 atm. symmetry targets with ultra-thin 1000A polyimide windows. [M. A. Salazar, *et al., Fusion Tech.* **25**, No. 5, 1829 (1995) and M. A. Salazar, *et al.*, 11th Target Fabrication Specialist's Meeting, WA (1996).]

- Filled glass micro balloons with up to 20 atm of DT at WETF. When shot at Omega, these targets produced the world's highest neutron yield. Los Alamos is replacing the capability of Mound which is being closed down. The current system can provide DT pressures in excess of those anticipated fro NIF beryllium targets and room temperature ignition targets. [A. Nobile, *et al., Fusion Technology*, submitted for publication]

- Assisted General Atomics with redesign of the Omega cryogenic target handling system. Los Alamos tritium expertise used in the weapons program is being applied in the design of the Omega system. Our recommendations included simplification of the system to assist tritium compatibility. We are proceeding with the design of the extended glovebox and glovebox cleanup system for the Omega cryogenic target handling system.

- Recently completed a study of spider web exposure to tritium in a typical high pressure fill procedure to verify the Omega spider web is not adversely affected by tritium exposure during the DT fill process.

  Background: Omega targets are mounted with spider webs that must survive a permeation fill of the target with near full strength.

- Fabricated and assembled first targets using the Cu/beryllium with gaps (to simulate a joint in a capsule) for hydro experiments at Nova.

- Target Deliveries including:

  Nova: 160 targets delivered for LANL experiments covering laser plasma instabilities, hydro, symmetry and foam buffered direct drive. Note: we provide all our targets for Nova, the only program to do so.

Fig. 6a. Machining fixture developed for fabrication of beryllium hemishells of 1-mm and 2-mm diameter, with surface finish specifications consistent with National Ignition Facility capsule designs.

Fig. 6b. A pair of beryllium hemishells machined and polished using the quick-flip locator. The hemishells have 2.1-mm diameter and 150-μm wall thickness.

Omega: 45 thin wall hohlraum targets, 35 planar foam-buffered direct drive targets, 50-60 polystyrene disks at 30 mg/cc and 50 mg/cc for use in LLE/LANL collaborative foam-buffered shots.

Vulcan/ Phebus: 95 foam buffered planar and cylindrical targets for collaborative experiments with Oswald Willi.

Trident : 1200 targets delivered for various ICF experiments.

- Completed preliminary experiments on beta-layering of solid DT inside a NIF-sized toroidal cylinder. These experiments were the first to show that, using only native beta-layering, DT ice can be prepared with an surface roughness of less than 1.0 micron rms (Fig. 7). Although this result was accomplished by keeping the cell at temperatures above 19 K, we also showed that the cell could be then quickly cooled to 18 K (the temperature for achieving the optimal initial central gas density) without any surface degradation. We furthermore showed that by enhancing the process with a few microwatts of heat from a central heater, a DT ice surface roughness below 0.5 microns rms could be achieved. [J. Hoffer, *et al., Fusion Technology*, **30**, 83-94, (1996); L. Foreman, *et al.,* to be published in Proceedings of 24th European Conference on Laser Interaction with Matter, Spain, (1996); J. Hoffer, *et al.*, ANS 12th Topical Meeting on the Technology of Fusion Energy, Nevada (1996) to be published in *Fusion Technology,* 1996]

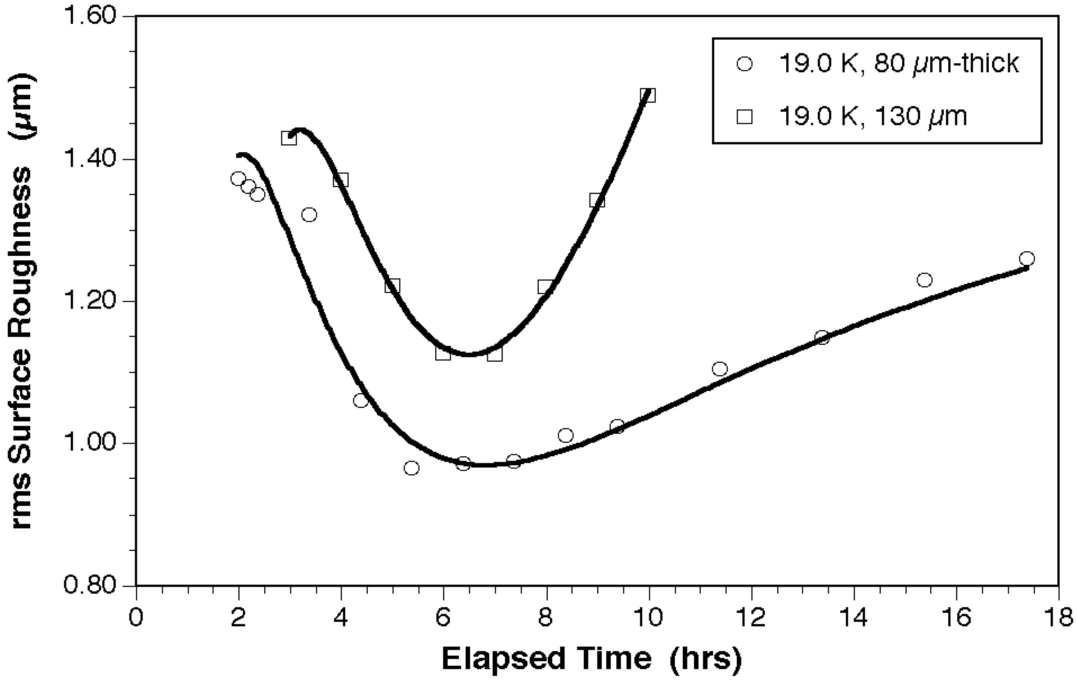

Fig. 7. Total rms surface roughness of solid D-T layers produced by native beta-layering at 19.0 K. At the 80 μm-thickness required for the NIF PT, the rms roughness minimizes just below 1.0 μm. After minimizing, the roughness increases due to ^{3}He build-up in the solid. In the thicker layer, more total ^{3}He is produced and the layer degrades more rapidly.

- Completed a thorough study of heat-assisted layering of pure deuterium. To understand the stochastics of the D_2 freeze-layering sequence, we developed techniques to make repeated experiments at the same average ice layer thickness. We have been able to put limits on the statistical variation in the total surface roughness amplitude as functions of temperature, layer thickness and heater power. In addition, this study has permitted us to experimentally verify the one-and two-dimensional models of heat-assisted beta-layering developed at Los Alamos and at LLNL. [J. Hoffer, *et al.*, 11th Target Fabrication Specialists Meeting, WA, 1996]

V. Computational Assessment

ICF computational assessment underpins demonstrating ignition on NIF, establishing fabrication requirements, guiding and interpreting experiments, as well as improving the predictive capability for the core weapons program. The two principal components of the computational assessment program are ignition target studies and advanced code development.

Ignition Target Design

Improvements in ignition target design and robustness studies, as well as the need to assess the accuracy of our calculational models, are the main factors that guide our experimental campaigns. For example, details of ignition design calculations help define plasma conditions chosen for laser plasma instability experiments, requirements for time-dependent drive-symmetry diagnostics, and important processes to be investigated in hydrodynamic instability experiments. Continued research in this area will allow us to optimize experimental campaigns on the main physics issues of ignition, and to evolve experimental designs which are the best possible scaled-down representation of true NIF phenomena. Simulations have included integrated target modeling (ITM) and direct numerical simulation (DNS) techniques to optimize target behavior [W. J. Krauser, *et al., Phys. Plasmas* **3**, 2084 (1996)].

Los Alamos has taken the lead in developing ignition target designs based on beryllium ablator capsules. As described below, these designs show considerable promise for having more robust design parameters; for example, being more tolerant of target fabrication defects. The Los Alamos effort in beryllium work draws substantially on weapons experience in both target design and fabrication and represents another important synergism between ICF and core weapons.

Accomplishments:

· Developed a NIF hohlraum design that shows improved tolerance to laser pointing errors, utilizing three rings of laser illumination in each half of the hohlraum (Fig. 8), as opposed to two rings in the standard design. Such an illumination scheme is compatible with the current NIF architecture. It was inspired by our collaboration with French scientists at the Centre d'Etudes de Limeil-Valenton, who originated a similar design for their LMJ (Laser MegaJoule). [F. J. Swenson, *et al.*, *BAPS* **40**, 1695 (1995)]

· Developed a *non-cryogenic* NIF ignition capsule. It uses a beryllium ablator, which collides with an internal gold shell. Carried out a stability analysis for this capsule, using DNS, which indicates acceptable stability to perturbations of long and intermediate wavelength. Used ITM to arrive at a simple square laser pulse shape and hohlraum design that lead to successful ignition calculations. [D. B. Harris and W. S. Varnum, *BAPS* **41**, 1479 (1996)]

· Analyzed the sensitivity of the plastic-ablator NIF "PT" capsule to combinations of perturbations from radiation-drive asymmetry and roughness of the plastic and DT ice surfaces. Determined that calculations with nominal surface roughness and realistic P_2, P_4, P_6, and P_8 drive asymmetries ignite and burn successfully. [W. J. Krauser, *et al.*, *Phys. Plasmas* **3**, 2084 (1996)]

· Carried out ITM design of a NIF target using a beryllium-ablator capsule. Showed how choosing the proper density of gas to fill the hohlraum allows greater control over drive symmetry. Began work on ITM design for 250-eV beryllium capsule. [P. A. Bradley and D. C. Wilson, *BAPS* **41**, 1557 (1996)]

· Refined and improved DNS calculations of NIF PT capsule stability. Developed new estimate of 1.1-1.8 μm for location of "roughness cliff" (maximum tolerable surface roughness) for DT ice layer in 2D calculations, given 20 nm ablator roughness and scaled Nova capsule mode spectrum. Identified long-range mode coupling in DNS calculations, by which high modes suppress the growth of low modes. [F. J. Swenson and N. M. Hoffman, *BAPS* **41**, 1557 (1996)]

Radiation-Hydrodynamics Code Development

Crucial to the ICF program is development of computational tools to understand complex ICF target behavior. Development of computational tools in ICF often has direct relevance to improving the predictive capability for the stockpile. Large radiation hydrodynamics codes are used as the principal design tools for ICF experiments. While LASNEX is and will remain the workhorse 2-D radiation hydrodynamics code for the Los Alamos ICF program, we are beginning to explore development of 3-D predictive capabilities for ICF target analysis to address important issues such as hydrodynamic stability and the design of tetrahedral hohlraums.

Accomplishments:

- Implemented and tested a new hydrodynamics scheme which produces much more accurate results when applied to test problems with known analytic answers (high-Mach-number shock tube, Sedov blast wave, Noh converging flow, etc.). The technique uses a Van-Leer-limited tensor artificial viscosity.

- Implemented plasma-physics postprocessing capability to calculate linear gain coefficients for SBS and SRS in LASNEX calculations.

- Converted LASNEX to operate on two new platforms, the Cray C90 and J90, and upgraded the Cray operating system to UNICOS 8.0.

- Rewrote the TDG postprocessor code to operate on workstations as well as Cray computers.

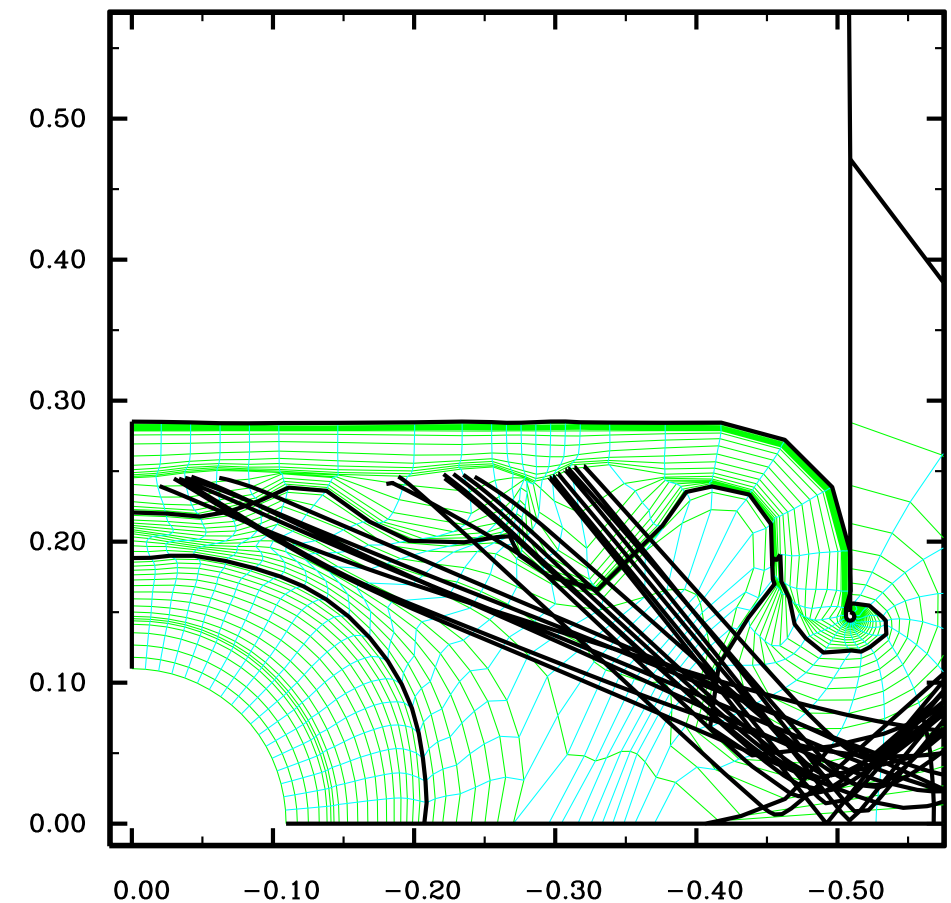

Fig. 8. Mesh plot for one quadrant of LASNEX NIF hohlraum calculation using three rings (per side) of laser illumination. A few representative laser rays are shown as heavy lines. Three “blisters” of ablated plasma are evident on the hohlraum wall where the laser rays terminate. Ablated plasma from one quadrant of the capsule is seen in the center of the hohraum. Ablated plasma from the wall is seen around the entrance hole.

- Adapted the radiation transport package to run in a scalar mode on the T3D, and distributed the computations over multiple processors, a first step to massively parallel code architectures.

- Began migration of LASNEX to scalar UNIX machines in anticipation of arrival of ASCI-Blue hardware.

- Enlarged the scope of quality-assurance and acceptance testing for new code versions, to include still more of the physics routines and user applications of interest.

Laser Plasma Instability Theory and Modeling

A variety of simulation codes are required in order to advance our understanding of parametric laser-plasma interactions. Depending on the nature (kinetic vs. fluid), and temporal and spatial scales of the particular parametric process under consideration, either particle-in-cell (PIC) or fluid models are appropriate. Massively-parallel, large-scale, fully three-dimensional plasma simulations that mimic experimental conditions will be a major thrust of the next 5-year period. Fluid models will be a more suitable description in other regimes. Neither of these methods of modeling the microphysics can be used to simulate the entire plasma on a NIF-relevant target. There is a need to develop "mesoscale" methods which relate the microphysics to the larger hydrodynamics scales.

Accomplishments:

- Developed a two-dimensional Particle-in-Cell code to study ion-driven parametric instabilities. The code was developed specifically for both workstation platforms and the CRAY/YMP. [H. X. Vu, *J. Comput. Phys.* **124**, 417 (1996)]

- Developed a one-dimensional Particle-in-Cell code to simulate the interaction between SBS and SRS. Here, both electrons and ions are treated as finite-size particles, and kinetic effects are therefore modeled properly for both electrons and ions. The field equations are treated by a novel method that allows the code the ability to simulated long time scales (~100 ps). This code is currently used to model the competition between SBS and SRS that has been observed experimentally.

- Developed a three-dimensional extension of the code described above. This three-dimensional code is specifically developed to run on the massively parallel CRAY-T3D. The code has been applied to study the role of nonlinear ion kinetic effects and the role of Stimulated Brillouin Scattering in the laser beam bending processes (due to transverse plasma flows; Fig. 9). These simulations are in fact the most advanced simulations ever performed in the area of laser-plasma interactions. [H. X. Vu, *J. Comput. Phys.* submitted, 1996]

- Developed a theoretical description for laser-beam deflection by plasma flow aided by filamentation [H. A. Rose, *Phys. Plasmas* **3** 1709 (1996)]

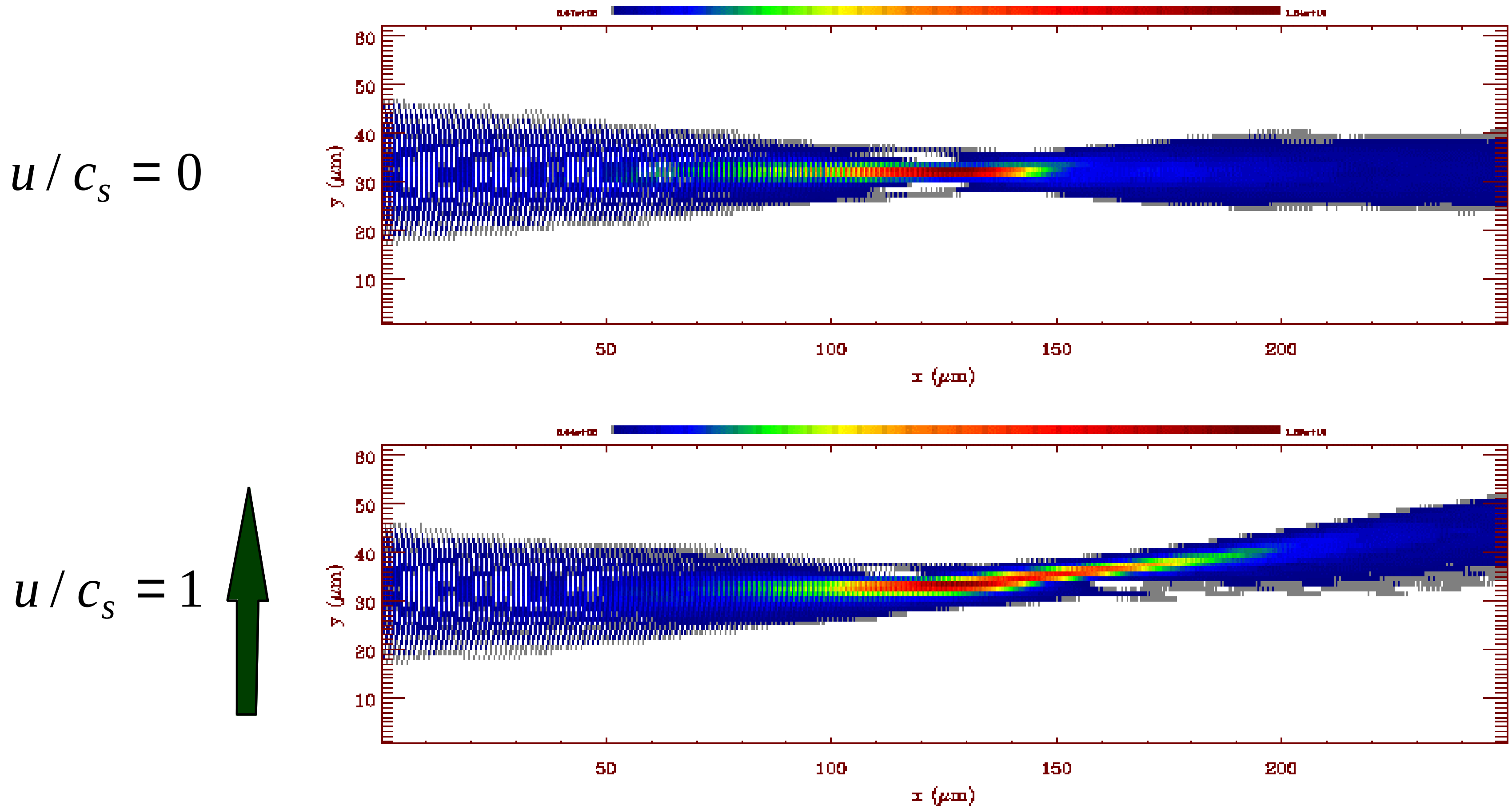

Fig. 9. Simulations of laser beam deflection by flowing plasma, from HERCULES 3D particle-in-cell code. Upper panel shows undeflected beam in the case of no lateral flow. Lower panel shows deflection of beam for transverse flow at Mach number = 1

- Developed a 3-D particle-in-cell code to study ion-driven parametric instabilities [H. X. Vu, et al., submitted to *Phys. Plasmas*]. The code uses ion particles in a background electron fluid, which greatly speeds computational speeds. The code has been developed for the massively parallel T3D platform. It is intended to study ion kinetic effects. It has been used successfully to model beam deflection experiments at the Janus laser at LLNL.

- Developed a fluid model which describes how self-consistent plasma flows generated by SBS and SRS can lead to flow inhomogeneities which can saturate SBS [H. A. Rose, submitted to *Phys. Plasmas*].

- Developed an approximate analytical model of beam deflection applicable to unsmoothed Nova beams [B. Bezzerides, *BAPS* **41**, 1599 (1996)].

- Developed a model to evaluate the range of electron temperature and density where secondary decay processes can saturate SRS [J. C. Fernandez, *et al., PRL* **77**, 2702 (1996)].

VI. Target Experimental Technology

Target experimental technology includes experimental capabilities which are essential in utilization of ICF facilities. At Los Alamos, these capabilities include diagnostic development, optical fabrication technology development (for NIF), and maintenance and operation of the Trident laser facility.

Diagnostic Development

Diagnostic development is key to the success of ICF and to the successful use of the National Ignition Facility for both the pursuit of ignition and weapons Stewardship. Characterizing and tuning ICF hohlraums and capsule behavior underpins all ICF experiments and will be particularly challenging on NIF. Target modeling accurately sets the bounds for ignition target performance but cannot predict the exact conditions (e.g. the precise laser pointing) required for a particular design. These conditions must be determined through precise and very accurately diagnosed experiments. Significant resources need to be invested in diagnostic development in order for ICF facilities to be fully utilized for both high precision ICF experiments and weapons physics experiments. Technologies associated with ICF diagnostic development are built upon many of the diagnostic techniques used in the underground nuclear testing program and thus this activity is highly synergistic with mainline weapon concerns. In addition, the development of diagnostics for NIF will insure that new technologies will be incorporated into established techniques, and will assure that new technologies will continue to be developed.

Accomplishments:

- Finalized the testing and construction of a gated monochromatic x-ray imaging instrument which has now been installed on the Omega laser system. This multi-channel system is capable of imaging monochromatic target emission with 10 eV bandwidth, has spatial resolution of <7 μm, temporal resolution of 80 ps, and 13 X magnification. Observation of gated monochromatic images has important applications which include the measurement of the targets core size, areal density, and implosion symmetry [J. A. Oertel, *et al., RSI*, (1987)]. Narrow band x-ray imaging will greatly enhance the level of quantitative information in the diagnosis of high convergence implosions. This technique is applicable to both self emission and backlighting.

- Deployed at the Nova Laser the Axial Imager diagnostic, which can image scattered by parametric instabilities along the hohlraum axis, with spatial resolution of about 25 microns and temporal resolution down to 150 ps. [J. C. Fernandez, *et al.*, *RSI* **66**, 626 (1996); W. M. Wood, *et al.*, *BAPS* **41** (1996)]

- We have obtained from VNIIEF an eight-channel soft x-ray spectrometer for measuring the radiation temperature in hohlraums. The instrument employs LSM mirrors and filters for each channel to provide higher resolution bandpass than the Dante spectrometer at Nova. The spectrometer was tested on the Trident laser gold disk targets and submillimeter hohlraums (radiation temperatures are consistent with values in the range 125 - 150 eV).

- Deployed the Oblique Scatter Array (OSA) to evaluate SBS sidescatter from Nova targets [J. C. Fernandez, *et al., RSI* **66**, 626 (1995)] OSA consists of a diode array for SBS or SRS calorimetry, as well as a fiber array-streak camera combination to measure the scattered power history.

- Developed new absorption spectroscopy techniques to examine shock heated material (UNR). This method can also be applied to fundamental investigation of materials properties that are of interest to both ICF and core weapons issues.

- Built a 16 channel gated x-ray imager based on pinhole imaging and microchannel plate gating in support of foam buffered direct drive shots on the Vulcan laser located in England. This instrument is similar in operation to those developed by Los Alamos for use on Nova and planned for the National Ignition Facility. It was built in under three months, transported to the Vulcan laser in England, and operated well on the initial foam-buffered hydrodynamics campaign.

- Developed a method for measuring low temperature shock heating of materials based on transient x-ray diffraction (Fig. 10). The method is based on the diffraction of fast bursts of laser generated x-rays being diffracted from crystalline material being compressed by to low to moderate pressure shock waves. The measurements provide information on the shock wave itself and on important properties of the material state such the onset of melt. This technique has significant applications to materials issues that are of importance to the weapons program.

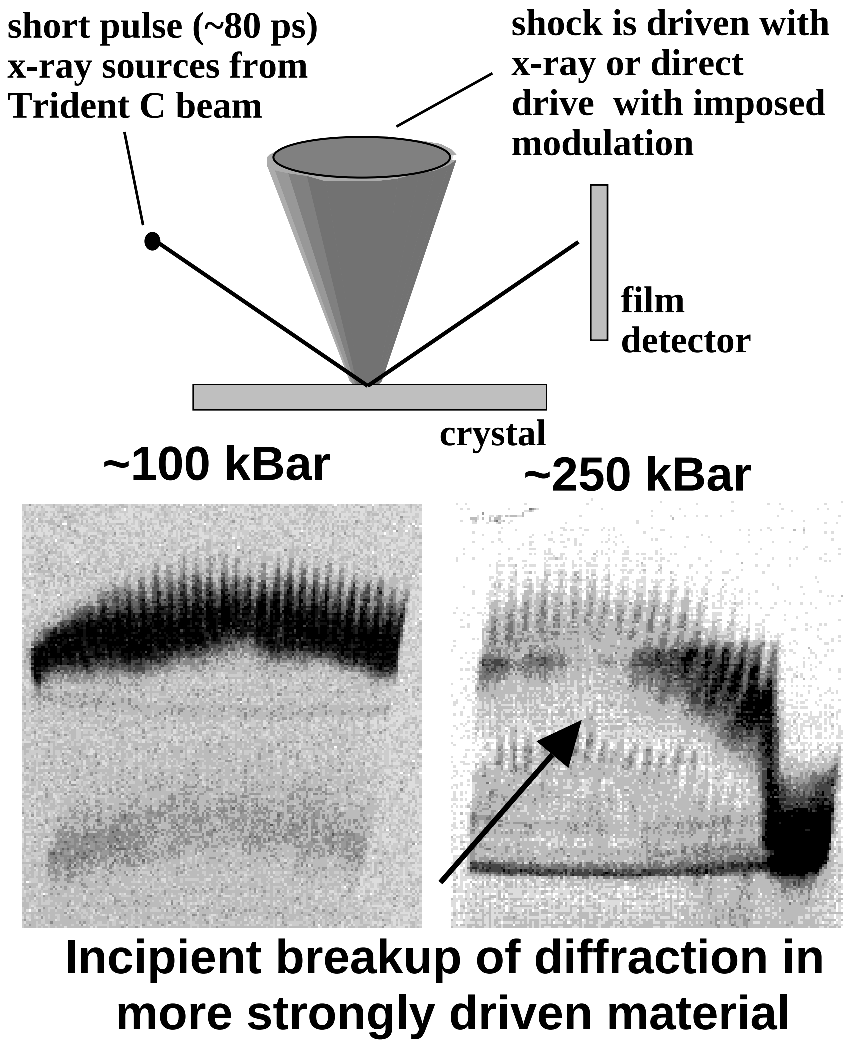

Fig. 10. Transient x-ray diffraction can be used to study melt and the propagation of modulated shocks.

- Developed and tested the Full Aperture Beam Station Imager (FABSI) backscatter imaging diagnostic which will be critical to spatially and spectrally characterizing laser plasma instabilities in hohlraums. Demonstrated 20 μm resolution in white light in the lab with FABS imaging diagnostic. Deployed FABSI at Nova. [J. C. Fernandez, et al., *RSI* **66** (1995) 626]. FABSI has succeeded in the very difficult technical challenge of imaging through a random-phase plate (using an inverse compensator plate) with better than 25 micron resolution and 150 ps gating time.

- Used improved analysis techniques to demonstrate better agreement between diagnostics of burn-averaged ion temperatures in ICF capsules. This effort resulted in better understanding of the effects of scattered neutrons in large single-hit arrays [R. E. Chrien, *et al*., *RSI* to be published 1996], and in an improved technique for determining ion temperatures from current-mode detectors at low yields [T. J. Murphy, *et al., RSI,* to be published, 1996].

- Finished the conceptual design for a low-yield bang time detector for use in indirect-drive experiments on Omega. This instrument will allow determination of the average time of neutron emission from targets yielding as low as 10^8 DD neutrons, a range common in indirect drive, but substantially lower than expected for Omega direct drive targets.

- Began conceptual design of a streaked optical pyrometer for Omega. This instrument will be used for hohlraum radiation temperature measurements and for equation of state measurements on Omega. These are requirements of high priority for the LANL ICF and Laser HEDP programs and less likely to be added by the LLE program due to their direct-drive emphasis, but will be useful for direct-drive shock breakout measurements as well.

- Interfaced commercial CCD camera to a Los Alamos standard gated x-ray imager. This technology will eventually break our dependence on film based cameras, which are labor intensive and slower than computer based readout systems. This technology is also important to the development of NIF type diagnostics.

- Developed in house technology for the designing, building, and testing of MCP based gated x-ray systems. This includes cathode deposition on MCP's, phosphor deposition on fiber faceplates, testing with various static x-ray sources, and temporal resolution measurements by 5 ps laser pulses.

- Performed Title I design of the NIF Time Resolved X-Ray Imager (TRXI). This instrument, based on the LANL GXI's used on Nova, will be built to verify beam pointing, spot size, and beam smoothing on the NIF. Estimates of the cost and schedule for this diagnostic have been developed. This instrument is designed to be upgradable to be used in preliminary implosion experiments.

Trident:

Trident is Los Alamos National Laboratory's multipurpose laboratory for developing instrumentation and conducting experiments requiring high-energy laser-light pulses. As a user facility, it is operated primarily for Inertial Confinement Fusion (ICF) research, weapons physics, and basic research. Featured are flexible driver characteristics and illumination geometries, broad resident diagnostic capability, and flexible scheduling.
The Trident facility includes a frequency-doubled Nd:glass laser driver, a high-vacuum target chamber, a basic optical and x-ray diagnostics suite, and ancillary equipment and facilities. A dedicated staff maintains and operates the facility and assists visiting experimenters.

The principal resource at Trident is the laser driver. It employs a Nd:YLF master oscillator and a chain of Nd:phosphate glass rod and disk amplifiers in conventional master-oscillator, power amplifier (MOPA) architecture. The oscillator output pulse is temporarily shaped, amplified, split into two beams, amplified again, frequency-doubled, transported, and focused to target. A third beam line can be used as an optical probe or to provide x-ray backlighting capability. Its pulse can be either 100 ps in length or the same length and shape as those of the main drive beams. Although it is normally operated at 527 nm, fundamental (1054 nm) output of the third beamline can also be used directly in the target chamber. The third beam can be timed to occur before or up to 5 ns after the main drive beams. The output of the master oscillator may also be frequency-broadened and "chirped" before amplification to allow compression to subpicosecond pulse lengths. Compressed pulses are presently available at the 1- 2 J level at a separate target chamber in the front end, and we are anticipating compression of higher-energy pulses in the future.

Trident boasts a full suite of target diagnostics. Optical diagnostics include illumination and backscattered light calorimeters, backscattered light spectrometers, and high-bandwidth (5-GHz) and streak-camera-based power monitors. Target x-ray emission is monitored by filtered, photoconductive diamond detectors and an x-ray streak camera with <10 ps resolution. Gated, filtered x-ray images covering 1 ns in 16 images are provided with 80-ps resolution by a Nova standard gated x-ray imager. Various filtered x-ray power and spectral diagnostics can be installed as needed. These cover the energy range of 0 to 35 keV. Static x-ray pinhole cameras are also available. Most optical and target diagnostics are available for either the main target chamber or the ultrahigh-irradiance chamber.

Trident has been critical to diagnostic development in the National ICF program and has played a key role in resolving fundamental plasma instability physics and studies of foam buffered direct drive. Additionally, Trident is used for a variety of weapons physics experiments, as a cost-effective staging area for experiments on Nova (and other facilities), and has underpinned the program of external collaborations at Los Alamos. The Trident facility will continue to perform 800-1000 high energy target shots/year in support of Nova and Omega experimental campaigns as well as weapons physics, ICF and university user experimentation.

Accomplishments

- Completed on budget and schedule a GPP addition to Trident which doubled the operational space and significantly improved laboratory cleanliness, accommodation of visiting experimentalists, and target area flexibility. This greatly enhances the efficiency of performing experiments for the development of experimental techniques, instrument development and calibration, and the prototyping of experiments to be performed at larger facilities.

- Maintained an experimental shot rate of 80 shots per month.

- In collaboration with University groups from Imperial College, University of Nevada, The University of Michigan, Oxford University, University of Rochester, and other institutions performed crucial experiments in many areas relevant to ICF physics. This kind of interaction has not only provided very valuable information for the ICF program but is a paradigm for the involvement of the academic community in the program and valuable precursor to the broader program of University envisioned by DOE. The following ICF and ICF-related experiments were conducted during the past year:

  - Beam deflection [B. Bauer, *et al., BAPS*, **41** (1996)]

  - Direct-drive imprinting

  - Foam buffering [R. G. Watt, *et al., BAPS* **41** (1996); M. Dunne, *et al., Phys. Rev. Lett.* **75** 3858 (1995); R. G. Watt, *et al., BAPS* **40**, 1785 (1995)]

  - Colliding shocks [Y. Xin, *et al.,* APS Topical Conf. on Atomic Processes in Plasmas, 1996]

  - Colliding plasmas [M. E. Jones, *et al., BAPS* **40** (1995); M. Wilke, *et al., Proc. SPIE* **2523**, 229 (1995)]

  - Ion wave saturation [R. P. Drake, *et al., Phys. Rev. Lett.* **77**, 79 (1996)]

- Continuum spectroscopy of low-Z elements [R. C. Elton, *et al., BAPS* **40**, 1806 (1995)]

- Vishniac instability

- Fast ignitor studies

- SBS [B. S. Bauer, *et al., BAPS* **40** (1995); R. P. Drake, *et al., Phys. Rev. Lett.,* (1995); P. Drake, *BAPS* **41** (1996); R. G. Watt, et al., Anomalous Abs. Conf. (1995)]

- Equation-of-state technique development [J. S. Wark, *et al., BAPS* **41** (1996); A. Hauer, *et al., BAPS* **41** (1996)]

· Diagnostics development efforts during the past year included:

- Monochromatic imager (UR/LLE-LANL) [F. J. Marshall, *et al., BAPS* **40** (1995); J. A. Oertel, *et al., Proc. SPIE* **2549** 82 (1995)]
- Plasma calorimeter (UR/LLE)
- X-ray spectrometer (LANL) [J. A. Cobble and S. Han, *BAPS* **41** (1996)]
- GXI (LANL)
- Radiation temperature (VNIIEF)
- PIN diode calibration (LLNL)
- NIF detector characterization [Davis, DSWA (formerly DNA)]

Optical Fabrication & Laser Science

Current optical fabrication costs and schedules present a significant risk to NIF. In collaboration with LLNL and the optics industry, the Los Alamos ICF program supports small focused technology development in this area as well as in the area of nonlinear optics. The proposed increase in the NIF shot rate and the desire for higher peak powers and improved beam quality to better support NIF weapons physics users motivate this avenue of technology development.

Accomplishments

· The Rapid Pad Polishing technique has been successfully applied to 35 cm square substrates to rapidly bring ground substrates to better than one wave figure error. This process is being scaled to handle two NIF-sized slabs (each 40 cm x 80 cm).

· Measured nonlinear index coefficients needed for finalizing the design of optical components in the NIF Title 1 have been measured by two methods: Z-scan and Frequency-Resolved Optical Gating.

Background: Considerable disparity existed in measurements of the nonlinear index of refraction for fused silica at the third-harmonic wavelength, and some bulk damage observed in Nova target lenses raised concerns over whether the sizes chosen for the NIF final optics might need to be increased to avoid damage initiated by self-focusing. Our measurements of nonlinear refractive index by two different techniques were in agreement with the lower range of previous measurements, indicating that it should not be necessary to further increase the optics size to avoid damage caused by this mechanism. A possible cause for this damage is discussed below. We also measured the nonlinear index for the type of laser glass to be used in NIF, as well as KDP and other materials.

- Measured the ratio of Raman gain in oxygen to that in nitrogen to confirm calculations of the maximum path for laser pulses in breathable oxygen mixtures that can be tolerated in the NIF design.

  Background: It is well documented that Raman scattering from nitrogen places a limitation on the intensity that can be propagated over long air paths. The NIF conceptual design considered using a breathable oxygen/argon mixture in part of the beam path to mitigate this problem. Our calculations, supported by our subsequent experiments, showed that the Raman gain in oxygen was sufficiently high to limit the increase in threshold intensity that could be achieved in this way to approximately 25%. For the highest desired intensities to be propagated to the target area in NIF, it appears that a more robust solution will be needed; e.g. inert gas beam tubes. We are also examining the mitigating effect of smoothing by spectral dispersion (SSD) on the Raman threshold. Experiments at Rochester showed substantial increase in Raman threshold with SSD, but the magnitude of this benefit is not well characterized.

Elucidated the importance of phase ripple effects on third harmonic conversion efficiency and identified designs for efficient broad-bandwidth conversion geometries.

Background: The effect of phase ripples on the input beam to the doubling and tripling crystals (e.g. from optical phase aberrations, diffraction effects, or diamond turning marks on crystals) was shown to have a substantial detrimental effect on tripling efficiency. Designs with two doubling crystals which gave increased conversion efficiency for a high-dynamic-range pulse were shown to be less sensitive to these phase ripples. We have also shown that similar converter designs can produce smaller intensity and phase ripples in the third harmonic output. The increase in amplitude of these intensity and phase ripples using single-doubler converter designs are believed to have been responsible for the initiation of bulk damage on Nova target lenses. Broad-bandwidth designs using two tripler crystals have also been studied.

Los Alamos Inertial Confinement Fusion

Selected Publications of 1996

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